

forn pattern, and standardized, have been distributed to some twenty-seven stations in the United States, ranging from Orono, Maine, on the east, to California on the west, and from Bozeman, Montana, on the north, to Gainesville, Florida, on the south, covering a wide range of altitude and of nearness to large bodies of water. Of these instruments, those received at the garden were Nos. 28, 30, and 34. It is hoped by means of the investigation to be able to establish a unit for measuring evaporation.

On the 6th of June, 1907, the evaporimeters were installed at three stations within the garden. These instruments consist of a pint fruit jar tightly corked with a cork stopper soaked in paraffine. Thru the stopper a glass tube extends from the bottom of the jar up and thru a second cork which tightly closes the opening into a porous clay thimble. The glass tube extends to the top of the thimble. For further protection against the entrance of water from without a paraffined piece of cloth was fitted tightly around the glass tube, and extended as a roof over the top of the fruit jar.

The jar was filled with distilled water up to a zero mark, and the porous thimble and the glass tube were also filled with distilled water. Each evaporimeter was sunk into the ground to the level of the top of the fruit jar. As evaporation took place from the surface of the thimble the water rose from the jar up thru the glass tube, thus keeping the thimble full and lowering the surface of the water in the jar. The rate of evaporation varied with the relative humidity of the surrounding air, and the amount was measured by carefully pouring more distilled water into the jar from a graduate until the water surface in the jar rose again to the zero mark. The amount of water necessary to accomplish this was the measure of the amount of evaporation for the given period.

Station 1 (evaporimeter No. 18) was west of the propagating houses on a dry, rocky knoll, covered with only a thin layer (one to two feet) of soil, and well drained. The instrument was shaded on all sides by tall saplings of red cedar and alanthus, and numerous small herbaceous plants and vines such as smilax rotundifolia and ferns. The surface of the ground was covered with twigs and dead leaves. Station 2 (evaporimeter No. 30) was about fifty feet south of the stable near the eastern border of the garden. The ground is low, poorly drained, and marshy during the spring and other periods of wet weather. The instrument was surrounded with unmoved grassy sod, shaded by a tall sapling of alder on the west, and by tall shrubbery (forsythia, etc.) on the east. Station 3 (evaporimeter No. 34) was about six feet east of the instrument shelter in the experiment garden (fig. 37, omitted). On the north and west was sod, on the east and south cultivated ground, with evening primroses within two feet. The soil here is loamy and well drained.

The photograph (omitted) shows the above-ground portion of the evaporimeter near the tall fence post. Evaporation takes place only from the upper (whiter) part of the porous clay thimble. The top of the fruit jar which is sunk into the ground is covered by the paraffined cloth "roof," thru which the glass tube passes from the jar into the clay thimble.

The instruments were all standardized by Doctor Livingston, so that, after applying the correction for each instrument, the respective readings were strictly comparable, varying only with the external conditions that control evaporation. Readings taken every week on Monday morning from June 6 to October 14, 1907, and standardized by applying the necessary correction constant, are given in the following table.

It has been ascertained by Doctor Livingston that an evaporation of 6.05 cc. from the evaporimeters corresponds to 1 mm. of depth, or, in English units (since it is customary to measure precipitation in inches), 153.67 cc. of evaporation equals 1 inch of depth. For the purpose of ascertaining these data comparisons were made between the evaporation from the evapo-

rimeters and from a chemical water bath, 25.6 inches in diameter, with the water standing 11 cm. deep when the surface is at zero on the scale. "It stands," writes Doctor Livingston, "with the water-surface level with the middle of the evaporimeters to be tested, and about two meters away from them. It is about 15 cm. from the ground to the water level. This level is about 5 mm. below the level of the dish at the beginning of a period, and the vessel is refilled once a day when the readings are made."

Week ending.	No. 28.	No. 30.	No. 34.	Week ending.	No. 28.	No. 30.	No. 34.
June 10, 1907 .....	66	48	.....	Aug. 19, 1907.....	126	80	188
June 17, 1907.....	77	48	129	Aug. 26, 1907.....	105	64	131
June 24, 1907.....	98	51	147	Sept. 2, 1907.....	118	85	128
July 1, 1907.....	60	29	106	Sept. 9, 1907.....	47	32	41
July 8, 1907.....	77	47	137	Sept. 16, 1907.....	74	41	85
July 15, 1907.....	99	55	129	Sept. 23, 1907.....	50	27	58
July 22, 1907.....	60	37	124	Sept. 30, 1907.....	50	.....	35
July 29, 1907.....	130	56	185	Oct. 7, 1907.....	99	32	80
Aug. 5, 1907.....	98	37	132	Oct. 14, 1907.....	68	.....	61
Aug. 12, 1907.....	82	46	142				

The total precipitation registered at the garden from June 10, 1907, to September 23, 1907, was 9.32 inches. This amount will be approximately the same for all three evaporimeter stations.<sup>3</sup> Therefore, taking the difference between the amount of precipitation in inches and the amount of evaporation from the evaporimeters in inches, we have:

For No. 28 (at the propagating house).... 9.32 in. — 8.47 in. = .85 in.  
 For No. 30 (at the stable)..... 9.32 in. — 4.84 in. = 4.48 in.  
 For No. 34 (at the experiment garden).... 9.32 in. — 12.10 in. = —21.42 in.

That is, at the propagating house precipitation was .85 inch in excess of the loss from the evaporimeter; at the swampy region, near the stable, 4.48 inches; while in the experiment garden during the same period the evaporating power of the air was 2.78 inches in excess of the precipitation recorded.

Now it should be kept in mind that the loss of water from the evaporimeters is not a measure of the amount of water lost by the soil thru evaporation, but is *only an index of the evaporating power of the air for the given station*. For the same locality the rate of evaporation from soil and from evaporimeter will materially differ, being less from soil and varying with its nature and condition, as well as with the surroundings above the soil surface.

The purpose of the above data, therefore, is not to give a measure of the amount of precipitation that remains in the soil, or that becomes available to the plants, but, as already emphasized, to give a measure of the evaporating power of the air in different localities. The above record, then, gives *numerical expression* of the fact that, of the three localities studied, the evaporating power of the air is greatest in the experiment garden, least at the swampy area near the stable, and intermediate on the elevated, shaded, and well drained rocky knoll.

#### RADIUM: ITS PROPERTIES, DISTRIBUTION, AND INFLUENCE ON THE ATMOSPHERE.

By W. W. STRONG. Dated Baltimore, Md., November 12, 1907.

##### THE RADIOACTIVITY OF RADIUM.

In communicating this memoir to the MONTHLY WEATHER REVIEW the author would remark that while the presence of the radium emanation in the air has not as yet led to any fundamental meteorological discoveries, yet I think it may clear up many points in atmospheric electricity. I believe that the ionization produced by the  $\alpha$  particles of the emanation and "radium C" plays a considerable rôle in the formation of nuclei for raindrops to condense upon.

Ramsay discovered small quantities of helium, argon, and neon in the air. These may be disintegration products of radium also.

<sup>3</sup>This may be far from true; there should be a gage near and at the level of each evaporimeter.—EDITOR.

On the whole then, I believe that this subject will in the end serve to clear up many outstanding phenomena even if it does not directly aid in predicting the weather.

This summer I was very much surprised to find an enormous (relatively) amount of external radiation during the forenoon—from 8 a. m. until 2 or 3 p. m. This may be due to the expansion of the air in the soil and an increase of emanating power due to the heating by the sunshine, or it may be due a change of the barometric pressure. It is to be noted that thunderstorms usually follow periods when the emanating power of the ground has been quite large. So it is quite possible that the emanation may have a rôle to play, altho not a fundamental one.

Any substance that possesses the power of making a gas become a conductor of electricity by producing in it a greater number of positively and negatively charged carriers of electricity is said to be radioactive. The best known radioactive substance is radium, discovered by the Curies in 1898.

Radium has been found to emit spontaneously and continuously a flight of material particles, projected with an enormous velocity, and also to be the source of radiations similar to X-rays and called  $\gamma$ -rays. The material particles consist of positively charged particles shot out with a velocity approaching that of light. They are readily absorbed by thin sheets of metal foil or by a few centimeters of air, and resemble the canal rays formed in vacuum tubes during electrical discharges. It is found that homogeneous  $\alpha$  particles, that is,  $\alpha$  particles with the same velocity, cease to ionize the air, to produce photographic action on a sensitive plate or to produce phosphorescence on a screen like zinc sulphide after having gone a certain definite distance from their source. This distance is called the range of the  $\alpha$  particle.

If the  $\alpha$  particles are traveling in the air under standard conditions of pressure and temperature, then the greatest distance the  $\alpha$  particles ionize the gas from the radioactive body will give the range of the  $\alpha$  particles in centimeters.

The  $\beta$  particles are found to carry a negative charge and to be the same as the corpuscles found in electrical discharges in vacuum tubes. They carry the same charge as an ion of hydrogen in electrolysis and possess a mass equal to about  $\frac{1}{700}$ th that of the hydrogen atom. In passing thru matter, they are absorbed according to an exponential law and do not possess a definite range as do the  $\alpha$  particles. The  $\beta$  particles are far more penetrating than the  $\alpha$  particles and are projected with velocities almost as great as the velocity of light. The  $\alpha$  particles produce the greatest amount of ionization, the  $\gamma$ -rays the least. With a thin layer of radioactive matter spread over the two plates, say 5 centimeters apart, it will be found that the relative order of ionization due to  $\alpha$ ,  $\beta$ , and  $\gamma$  radiations is as 10,000 to 100 to 1, whereas the average penetrating power is inversely proportional to the relative ionization. Photographic action is due almost entirely to the  $\beta$  particles.

Another type of radiation is the  $\delta$ -rays which consists of slow moving corpuscles with a velocity of  $3.3 \times 10^7$  centimeters per second. It has been found that the bulk of the ionization produced by the  $\alpha$  particles consist of the displacement of the slow moving corpuscles from the atoms of the substance traversed, i. e., of the production of  $\delta$ -rays. Bragg believes that  $\beta$  particles also produce  $\delta$ -rays, and that  $\delta$ -rays produced in various ways and under different physical and chemical conditions all possess the same velocity.

The radioactivity of the radio-elements is not a molecular, but an atomic property and the rate of emission of the radiations depends upon the amount of the element present, and is believed to be unaffected by the application of any known physical or chemical forces. Any product will decay according to the exponential law  $N = N_0 e^{-\lambda t}$  where  $N$  is the number of particles unchanged after a time  $t$ ,  $N_0$  is the initial number

of particles, and  $\lambda$  is the constant of change. Since  $dN/dt = -\lambda N$ , the rate of change at any time is always proportional to the amount of matter unchanged. This theory has been of enormous service in interpreting radio-active phenomena and in suggesting new lines of work. At present the theory and fact agree. To explain the emission of positively and negatively charged particles, Rutherford and others consider the radio-elements as undergoing spontaneous changes and that the energy of projection of the  $\alpha$  and  $\beta$  particles had previously been stored up in the atom as rapid oscillatory or orbital motion. This breaking up of the atom is considered to be accompanied by the production of a series of new substances which have distinct physical and chemical properties. These products are not produced simultaneously but arise in consequence of a succession of changes originating in the radio-element. For instance radium is an element very closely allied in chemical properties to barium. It has a definite spectrum of bright lines similar in many respects to the spectra of the alkaline earths. Now, if a radium compound is dissolved in water and boiled for some time it is found on evaporation that the activity has been diminished by 75 per cent. This loss of activity is due to the escape of the direct decomposition product of radium by the process of boiling. This product is called the emanation and is an inert gas. This gas is extremely radioactive and condenses at  $-185^\circ$  C. In respect to its spectrum and absence of any definite chemical properties, it resembles the argon-helium group of inert gases. The emanation is to be considered an unstable gas which breaks down into a nonvolatile type of matter, the disintegration being accompanied by the projection of an  $\alpha$  particle. The nonvolatile matter produced from the emanation has been broken up into several products, radium A, radium B, radium C, etc. The rate of breaking up of these products has not been found to be changed by the variation of the physical and chemical conditions under which they exist. For instance, Schuster has found no change in the activity of the emanation when subjected for four days to a pressure of 2,000 atmospheres. A. S. Eve found that a pressure of 20,000 atmospheres did not affect the radiation from radium C.

TABLE 1.—Radium family.

Product.	Time required to be half transformed.	Radiations.	Range of $\alpha$ particle.	Velocity of a particle cm./sec. $\pm 10\%$ .	Physical and chemical properties.	
Uranium .....	(10) <sup>9</sup> years.....	$\alpha$	<i>Cms.</i> 3.5	1.56	Soluble in excess of ammonium carbonate.	
Uranium X.....	22 days.....	$\beta, \gamma$			Insoluble in excess of ammonium carbonate.	
Ionium .....		$\alpha, \beta$	3		This element resembles thorium in chemical properties and gives off no emanation.	
Radium.....	1300 yrs.(about).	$\alpha$	3.5	1.56	Allied chemically to barium.	
Emanation.....	3.8 days.....	$\alpha$	4.33	1.69	Inert gas of heavy molecular weight.	
Active deposit of slow change.	Radium A.....	3 minutes.....	$\alpha$	4.83	1.76	The active deposit is concentrated on the cathode in an electric field.
	Radium B.....	26 minutes.....	Weak $\beta$			
	Radium C.....	19 minutes.....	$\alpha, \beta, \gamma$	7.06	2.06	
Active deposit of slow change.	Radium D.....	40 years.....	Rayless			Volatile below 1000° C.
	or Radiolead. Radium E.....	4.8 days.....	$\beta$			Stable at 1000° C.
	Radium E.....	6 days.....	Rayless			Volatile at red heat and soluble in acetic acid.
Active deposit of slow change.	Radium F.....	140 days.....	$\alpha, \delta$	3.86	1.62	Deposited on bismuth in solution.
	or Polonium. Lead.....		$\alpha(?)$	12		Radium D and F are often found in commercial lead.

The effects of a very wide variation in temperature has also been studied. All experimenters find no variation until very high temperatures are reached and here different results are obtained. Doctor Bronson has recently found that a temperature of 1,600° C. did not change the activity of the emanation, radium *A*, radium *B*, or radium *C*. A few of the properties of the various radioactive products will be given in Table 1.

Quite recently the atomic weight of radium has been re-determined by Mme. Curie. She obtained .4 grams of radium chloride, which was as pure as she could make it. The purification consisted in fractional crystallization and precipitation, these being controlled by the spark spectra. When the purification was stopt the brightest barium lines were very faint. The mean of three determinations (letting the atomic weight of silver be 107.8 and chlorine 35.4) was 226.45. The value of the atomic weight of the emanation has been found by the diffusion method and comes out from 85 to 100. Ramsay believes that the emanation usually exists in the diatomic condition and that it belongs to the argon-helium group of elements. If this is true, he shows that its molecular weight should be about 216.5.

Soon after the discovery of radium the very remarkable discovery was made that it was continually emitting heat energy. J. Precht has recently determined the heat energy given off by radium bromide freed from water of crystallization. His results show that 1 gram of radium emits 122.2 calories of heat energy per hour. Surrounding the radium with a lead screen 1 millimeter thick, this becomes 126.9 calories per hour; and for a screen 3 millimeters thick, 134.4 calories. An increase of the screen beyond a thickness of 3 millimeters did not increase the amount of heat energy given off by more than .1 calory per hour. Taking the mean speed of the  $\beta$  particles to be  $2.5 \times 10^{10}$  centimeters per second, then the total mass of the  $\beta$  particles emitted in one hour is  $1.6 \times 10^{-12}$  grams. Letting  $4.5 \times 10^{-24}$  be the mass of hydrogen molecule and knowing that a  $\beta$  particle possesses the mass of  $\frac{1}{718}$ th that of the hydrogen atom, one finds that 1 gram of radium emits  $2.2 \times 10^{10}$   $\beta$  particles per second.

Ramsay states that the emanation from 1 gram of radium evolves heat at the rate of 75 calories per hour. One cubic centimeter of the radium emanation would then give out a total heat energy of 7,000,000 gram calories. The chemical formation that produces the greatest amount of heat energy is the combination of hydrogen and oxygen in the proportion to make water. One cubic centimeter of this mixture will emit 3 gram calories in combining to form water.

#### THE $\alpha$ PARTICLES.

If  $e$  is the electric charge and  $m$  is the mass of the  $\alpha$  particle, the value  $e/m$  has been determined to be  $5.07 \times 10^8$  electromagnetic units. It thus follows that the radioactive elements and substances used in electric discharges have common particles whose value of  $e/m$  is the same as that of the  $\alpha$  and  $\beta$  particles and which also possess the same properties. Whether all bodies emit these particles under ordinary conditions has not been fully settled, but the experimental evidences indicate that they do. From the above we found that the  $\alpha$  particles cease to ionize the gas after traversing a distance which is equivalent to their range in air under normal conditions of pressure and temperature. Beyond this point the presence of the  $\alpha$  particle can not be detected, so that if  $\alpha$  particles were emitted by ordinary substances with a velocity less than the critical velocity their presence could not be detected by any known method.

The  $\beta$  particle is effective as an ionizing agent for about 100 centimeters producing about 130 ions per centimeter in air at standard conditions compared with 100,000 per centimeter produced by the  $\alpha$  particles. For radium in equilibrium one  $\beta$  particle is emitted for every four  $\alpha$  particles so that the  $\beta$  produce only about 1 per cent of the ionization.

The main source of the heat emission of radium is believed to be derived from the energy of the  $\alpha$  particle. A great deal of work has recently been done upon the properties of these very interesting  $\alpha$  particles. Not only are they emitted by radium, but by all the radio-elements and possibly by all metals. The  $\alpha$  particles of all the radio-elements are found to differ only in the velocity of their projection, this velocity determining their range. Otherwise the  $\alpha$  particles all appear alike.

For the  $\alpha$  products from the various products of radium, Rutherford has found the empirical relation

$$V = 0.348 V_0 \sqrt{r + 1.25}$$

to hold between the range of the  $\alpha$  particle and its velocity at any point in its path. Here  $V_0$  is the initial velocity of the  $\alpha$  particle emitted by radium *C* and is  $2.06 \times 10^9$  centimeters per second, and  $r$  is the remaining part of the range which the  $\alpha$  particle has to go from the point of its path which is being considered. From the above equation it follows that the initial velocity of expulsion of an  $\alpha$  particle from a given product would then be a constant.

The  $\gamma$  and X-rays are very penetrating and produce very few ions per centimeter of path. They are usually believed to be pulses in the ether. W. H. Bragg has recently brought forth the theory that they consist of an  $\alpha$  and  $\beta$  particle combined which have been shot off the radioactive atom. If this is true the electric field about this neutral particle would be very weak so that its penetrating power would be enormously increased. By means of this theory Bragg is enabled to explain many of the properties of the  $\gamma$ -rays.

Along an  $\alpha$  particle's path the ionization is found to increase considerably near the end of the range. Plotting ionization as abscissas and distances from the radioactive surface as ordinates one gets an ionization curve. The area between the curve and axes gives the total ionization in the gas. By experimental means these curves come out the same in form no matter what the nature of the absorbing substance. The stopping power is a function of the atom and is unaffected by its association with other atoms in the molecular structure, and is independent of pressure and temperature. That is to say, the range of the  $\alpha$  particle in a given gas can always be predicted from the composition of the gas molecule. Not only so, but stopping powers of various atoms are very nearly proportional to the square roots of atomic weights, both for gases and solids.

The  $\alpha$  particles expend the same amount of energy no matter what the gas is, but in different gases a different number of ions will be formed as the table shows; but the stopping power is a function of the atomic weight which the total ionization is not. Plainly, then, the energy spent by the  $\alpha$  particle and the resulting ionization are not directly connected. Bragg believes that there is a secondary ionization within the molecule. He shows that if  $\delta i$  is the ionization due to the expenditure of a small quantity of energy  $\delta e$ , then  $\delta i = \kappa f(V) \delta e$  where  $f(V)$  is a function of the velocity of the particle only and  $\kappa$  is a constant, being the specific ionization of a gas for the  $\alpha$  radiation. Bragg shows that  $f(V)$  is very probably  $1/V$ .

Considerable discussion has been held as to the nature of the  $\alpha$  particles. If they are particles of matter belonging to the known list of elements, their value of  $e/m$  would indicate that they were either hydrogen or helium. If they consist of helium atoms they must carry two charges, however. These charges it may possess on ejection or acquire afterward. On the other hand, if they consisted of hydrogen, then hydrogen would accumulate in radioactive substances. This has not been found to be the case altho there is always helium present, and it is only in radioactive minerals that helium has been found. The presence of a light, inert gas-like helium was a sort of surprise to radioactivity students and lead Rutherford

to predict that helium was a disintegration product of radium. Ramsay and Soddy took up the work. They found the emanation to act like a very inert gas and to give a characteristic spectrum. After leaving the emanation to remain several days they found that helium lines began to appear. Thus it was shown that helium was a transformation product of radium. Whether the helium is one of the final products of the disintegration of the emanation or whether it consists of the expelled  $\alpha$  particles has not been settled. Debiere has found that actinium also produces helium. Considerable helium has been found in thorium minerals indicating that helium is one of the products of the breaking down of thorium. But thorium and actinium have emanations like radium so that these facts do not aid in determining whether the  $\alpha$  particles are the source of helium or not. Once the rate at which helium is liberated is known, it will be possible to say more. By this means it will also be possible to estimate the age of a radioactive mineral by the amount of helium occluded. Assuming the  $\alpha$  particle to be helium, Rutherford has calculated the age of the minerals fergusonite and thorianite from their helium content and arrives at an age of about 400,000,000 years. In assuming radium and uranium to have attained radioactive equilibrium he finds that 1 gram of uranium will produce  $6.3 \times 10^{-8}$  cubic centimeters of helium per year.

DISTRIBUTION OF RADIUM.

Hitherto we have discussed the very remarkable properties of radium. Now its wide distribution will be considered. Quite recently Strutt and Eve have determined the radium content of a considerable number of rocks. As this work has a very great geological significance a few of the results will be given. A solution of a definite amount of the rock was stored until the equilibrium amount of radium emanation had accumulated. The amount of emanation was then measured and the radium content determined.

TABLE 2.—Distribution of radium.

Name of rock.	Location.	Radium per gram.
		<i>Grams.</i>
Granite.....	Rhodesia ...	$4.91 \times 10^{-12}$
Do.....	Cornwall.....	4.80 "
Blue ground.....	Kimberley.....	1.73 "
Leucite basanite.....	Vesuvius.....	1.71 "
Hornblende diorite.....	Heidelberg.....	1.08 "
Hornblende granite.....	Assouan, Egypt.....	1.26 "
Angite syenite.....	Norway.....	.95 "
Granite.....	Isle of Rum.....	.37 "
Basalt.....	Greenland.....	.31 "
Native iron.....	do.....	.22 "
Meteorite iron.....	Thunda.....	*
Do.....	Virginia.....	*
Do.....	Santa Catarina.....	*
Essexite.....	Canada, Devonian period.....	2.6 "
Tingualto.....	do.....	4.3 "
Do.....	do.....	3.0 "
Nephelino syenite.....	do.....	1.1 "
Oolite.....	Bath.....	3.00 "
Marble.....	East Lothian.....	1.99 "
Roofing slate.....	Wales.....	1.32 "
Clay.....	Essex.....	.89 "
Red chalk.....	Hunstanton.....	.55 "
White marble.....	India.....	.28 "
Chalk (bottom of pit).....	Cambridgeshire.....	.40 "
Chalk (top of pit).....	do.....	.12 "
Deposit, hot springs.....	Bath.....	.425 "
Cambridge tap water.....	do.....	.40 "
Sea salt.....	do.....	.077 "
Boiler crust.....	Cambridge.....	.04 "
Sea salt.....	Onaha.....	.020 "
Sea water.....	Atlantic.....	.003 "
Trenton limestone, crystalline.....	Canada, Ordovician.....	.92 "
Trenton limestone, weathered.....	do.....	.91 "
Boulder clay.....	Canada, Quaternary.....	.80 "
Leda clay.....	do.....	.78 "
Saxicava sand.....	do.....	.16 "

\* Indetectable.

These tables give typical examples of the rocks analyzed and show the wide distribution of radium in both igneous and sedimentary rocks. The average content of the rocks is high, whereas that of sea salt is quite small; the average for igneous is  $1.7 \times 10^{-12}$  grams of radium per gram and for sedimentary rocks  $1.1 \times 10^{-12}$ . The amount of radium content necessary to maintain the earth at a constant temperature is about  $1.75 \times 10^{-13}$

grams of radium per cubic centimeter of the earth. This is very much less than the radium content of any of the rocks. For this reason Strutt believes that radium is to be found only in the outer crust of the earth, at least if the earth is becoming cooler. In making his calculations Strutt does not consider the presence of radium and thorium and the possible radioactivity of ordinary materials. If the heating effect of ordinary substances is of the same order of magnitude as is to be expected from the ionization they produce, the earth's temperature gradient would be many times larger than that observed. Strutt believes this to be an argument against the view that ordinary matter possesses a natural radioactivity of its own.

C. B. Thwing claims, however, that he has been able to find a temperature gradient in small cylinders of the various metals and rocks. At present then the exact heating effect of the radioactive substances in the rocks is not known. J. Joly believes that the radium content of sedimentary rocks is greater than for igneous ones. Thick strata of sedimentary rocks might then be a very important element of mountain building by raising the temperature of the base of the mass. Joly finds that a specimen of red clay (2700 fathoms in North Atlantic) contained sixteen times as much radium as the average igneous rocks, and globigerina ooze (1990 fathoms, South Atlantic), six times as much.

Some very interesting work has recently been done by Strutt upon the content of helium and argon in the rocks, with results as shown in the following table:

TABLE 3.—Strutt's results.

Mineral.	Amount analyzed.	Nitrogen.	Argon.	Neon.	Helium.
Commercial pumice stone, Lipari Island	Grams. 480	cc. 3.5	cc. .049	Argon and neon	cc. None
Beryl.....	250	.....	.....	.....	4.2
Matopo granite.....	850	11	.14	Traces	.04
Syenite rock, Leicestershire.....	900	9	.026	Traces	.010
Bath.....	100	1.5	Traces	.....	.12
Forty springs in France.....	Present	Present	Present	.....	Present
Syenite, greenstone and red sandstone	Present	Present	Present	.....	Present

RADIOACTIVITY OF THE ATMOSPHERE.

After considerable work had been done upon ionization it was found that ordinary free air was ionized. Now in the table of transformation products of the radio-elements, it will be noticed that several of the products have the property of condensing upon a highly negatively-charged wire. Elster and Geitel tried exposing charged wires in the open air and found that an active deposit of radium and thorium formed on the wire. The amount of active deposit was found to depend upon the locality and the weather conditions. If the air had been undisturbed for some time, as the air in caves and cellars, it was found that the active deposit formed was much greater. Air sucked thru the pores of the ground was found to be very active. Elster and Geitel concluded from these results that the radium and thorium emanations (which behave like gases) ooze thru the ground and percolating waters and have their origin in the radium and thorium of the soil. The emanation then breaks up into various products as given in Table 1. During this time the emanation gives rise to positively charged carriers, which are driven to a negatively charged wire by the electric field. It is to the emanation and its products that the ionization of the air is attributed.

Thorium C and radium C give off  $\gamma$  rays and as these are very penetrating, they would be the source of a very penetrating radiation, and this latter was discovered several years ago. The ionization in a closed vessel is measured, and thick lead screens are then placed around the electroscope, and the ionization again measured. The ionization in the latter case is found to be very considerably decreased, the penetrating radiation having been largely cut off. Whether all the pene-

trating radiation can be explained as due to radium *C* and thorium *C* will be taken up later.

As the potential of the earth is negative compared with that of the air, the active deposit is dragged down to the surface of the ground and upon the leaves and branches of plants and trees. A hill or mountain top concentrates the earth's field and so receives a greater amount of the active deposit.

In this way Elster and Geitel explain the greater ionization on hills and mountains. Experiments show that the active deposit tends to collect upon dust particles and these serve as nuclei for the condensation of raindrops and snowflakes. The deposit resulting from evaporating rain and snow should be very radioactive. This was found to be true by Wilson and Allen. Again a big rain or snow should carry down most of the active deposit, and as the emanation does not emit  $\gamma$  rays, the amount of  $\gamma$  radiation from the radioactive matter in the air should be very much decreased. The penetrating radiation, if it consists mainly of  $\gamma$  rays, should then become very small. This has been borne out by experiments made by the writer. As the emanation does not seem to be carried down by the snow and rain, the products, radium *C* and thorium *C*, would soon be in equilibrium again after a rain or snow. The experimental evidence indicates that the radiation comes mainly from products in the air and not from those in the ground. The amount of this penetrating radiation varies enormously.

The effect of the presence of radioactive matter in the atmosphere upon ordinary phenomena is perhaps very great, tho at present little is known. It has been found that deep wells and hot springs contain considerable radium. From this Elster and Geitel suggest that the curative effect of thermal springs and the physiological action of the air at high levels may be related to the large amount of radioactive matter present. The presence of radioactive matter, and therefore of ionization, in the air probably plays a very important rôle in the growth of plants. It has been found that vegetables grown in an atmosphere electrified positively are much above those grown in normal fields both in quantity and quality. The ionization and nucleation produced by radioactive matter in the air may be very essential for the condensation of rain and hail, and serve to explain the enormous accumulation of static electricity during thunderstorms.

Simpson and others have measured the activity of the air which has blown over the sea and have found it small. Now if most of the radium and thorium emanations come from the pores of the soil and underground cavities, the results obtained by the above investigators would be expected, for, as will be seen from Table 2, the radium content of ocean water is very small. Eve has recently measured the ionization over the ocean and has found it to be the same as the ionization over the land; a rather unexpected result. In this state the matter rests at present. A crucial test would be to expose negatively charged wires far out in the ocean and study the active deposit, or to test for the presence of a penetrating radiation. According to J. Joly, the distinguished geologist, Eve's results can easily be explained. Geologists have for some time made an approximate estimate of the age of the oceans by making determinations of the amount of salt which they contain. By analyzing the waters of rivers flowing into the ocean for the salt which they contain and determining the total annual outflow of all the rivers into the ocean, and supposing these constants to have been practically constant during the past, it is easy to make an estimate of the approximate age of the oceans. Now if radium and uranium always exist in a constant proportion, the present radium content of the ocean would have been supplied by the rivers in a comparatively short length of time. For this and other reasons Joly believes that uranium and radium are not always to

be found associated together. Now we know that radium has a short period of decay so that it must be constantly supplied from somewhere. Joly believes that the source is at least partly outside the earth. This radium is gradually being brought down to the surface. This would account for the ionization over the ocean and the wide distribution of radium over the earth. Elster and Geitel's theory of the escape of the emanation from the upper layers of the soil would still hold true. If radium exists outside the earth, it would be expected that the upper layers of the earth's atmosphere would be highly ionized by the  $\gamma$  rays. This highly ionizing radiation would serve to explain some of the phenomena of atmospheric electricity. According to C. T. R. Wilson, the positive potential of the atmosphere is largely to be attributed to the carrying down of negative charges by raindrops and snowflakes. The upper layers of the atmosphere, being highly ionized and quite good conductors, would conduct the remaining positive charge to places of lower potential, and would thus always aid in equalizing the potential of wet and dry regions.

#### FAMILY HISTORY OF RADIUM.

In unaltered minerals which have been formed during the same geological period and which contain radioactive elements, one would expect to find all the products of disintegration in radioactive equilibrium if the minerals were of sufficient age. If the minerals are not old enough for this radioactive equilibrium to have been established, then the proportion of each disintegration product with respect to the parent substance must be greater in those minerals which are the older and should correspond with the order of the respective geological ages of the localities in which the minerals have been formed. In secondary minerals, which have been formed by the subsequent alteration of the original primary minerals, the relative amounts of the disintegration products would be less than in the primary minerals from the same locality. For instance, if radium was a disintegration product of uranium, since radium has a comparatively short period of decay, we would expect to find a constant ratio between the amount of radium and the amount of uranium in a mineral. This has been found to be true. A large number of uranium minerals have been investigated, and it has been found that for every gram of uranium there are  $3.8 \times 10^{-7}$  grams of radium accompanying it.

Doctor Boltwood has investigated the ratio of the amounts of lead and uranium and of helium and uranium. He finds that the ratio of lead to uranium is constant for uranium minerals of the same locality. The ratio of helium to uranium has also been found to be fairly constant under the same conditions, altho on account of the ease of escape of helium one would not expect the figures to agree as closely. Following is a table containing some of Boltwood's results.

TABLE 4.—Boltwood's results.

Name of mineral.	Number of analyses.	Average per cent of uranium.	Average per cent of lead.	Average ratio of lead to uranium.	Locality.	Age of mineral in millions of years.
Uraninite.....	5	70.8	2.92	.041	Glastonbury, Conn.....	410
Uraninite.....	4	72.25	3.875	.0535	Branchville, Conn.....	535
Uraninite.....	3	73.66	3.8	.052	Spruce Pine, N. C.....	510
Uraninite.....	1	71.0	3.3	.046	Marietta, S. C.....	460
Uraninite and mackintoshite.	3	43.3	7.43	.18	Llano County, Texas.....	1,800
Samarksite.....	3	4.10	.80	.20	Douglas County, Colo.....	1,900
Uraninite.....	3	49.7	6.13	.13	Annerod, Norway.....	1,700
Thorianite.....	4	11.25	2.50	.22	Sabaragamuva Prov., Ceylon..	2,200
Thorianite.....	1	25.0	2.1	.086	Calle District, Ceylon.....	860

McCoy and Ross have made very careful estimates between the activity of a pure uranium compound and a uranium mineral, and have found the mineral to be 4.58 times as active as the corresponding pure uranium compound. The activity

of a quantity of uranium is 1.87 times as active as that of the radium in equilibrium with it. Now radium in equilibrium with the emanation and radium *A* and *C* is 5.64 times as active as radium alone. Now assuming radium *F* to have an activity in proportion to the range of its  $\alpha$  particles, it would be 1.10 times as active as radium. So radium and its products are 6.74 times as active as radium. A uranium mineral should be 6.74 + 1.87 or 8.61 times as active as the equilibrium amount of radium or 4.60 times as active as the uranium it contains.

These results show very conclusively that radium is a disintegration product of uranium.

If radium is considered a transformation product of uranium, as these and other experiments indicate, and further since the range of the  $\alpha$  particles of uranium and radium is the same, and if the activity is assumed proportional to the range, then for equilibrium amounts of uranium and radium there will be twice as many  $\alpha$  particles emitted by uranium as radium. But only one product of the uranium group emits  $\alpha$  particles, so that it seems very probable that there is a product between uranium and radium that emits  $\alpha$  particles.

Radium has been found to increase in amount in uranium and actinium solutions by Boltwood and Rutherford. Boltwood has succeeded in separating the radium parent from an actinium solution by precipitation with sodium thiosulphate. This radium parent he calls ionium and finds its activity about equal to that of radium in equilibrium with it. No emanation has been found as yet to issue from ionium. It emits very slow  $\alpha$  particles and resembles thorium in its chemical properties.

Soddy has recently dissolved uranium minerals in ether several times and has tried various methods of purifying his radioactive substances. Using 250 grams of uranium which has been dissolved in ether for several days, he finds no radium at the end of six hundred days. Neither could he detect any growth of actinium in a uranium solution or any radium in an actinium solution which he had purified. It thus seems quite probable that uranium breaks down into ionium, ionium into radium, and radium later on breaks down into lead. Whether actinium is related in any way to the radium family of elements is at present unknown.

THE RADIUM EMANATION.

The radium emanation is probably the most unique substance known. It was discovered in 1900 by Dorn. It was found to comport itself as an intensely radioactive gas. It was early found that the various compounds of radium differed very much as to the amount of emanation which they emitted under ordinary conditions. This emanating power is greatly increased by the presence of moisture. Radium chloride emits but little emanation in a dry gas, but when the surrounding gas becomes moist the emanating power is much greater. By solution or by the heating of a radium compound the amount of emanation set free is greatly increased. A solution of radium chloride has been found to have 200 times the emanating power of dry salt. Heating radium compounds to a red heat increases the emission of emanation 10,000 times. Cooling decreases the emission. The emanating power depends upon the physical and chemical conditions under which the radium exists. But the amount of emanation formed is entirely independent of these conditions.

The radium emanation possesses the greatest content of potential energy of any substance known. One cubic centimeter liberates 3,000,000 times as much heat energy as a cubic centimeter of hydrogen and oxygen mixt in the proportion to make water. A 1-pound weight of the emanation would at its maximum activity radiate energy at the rate of 10,000 horse power. Ramsay has found that the emanation is produced from 1 gram of radium at the rate of  $3 \times 10^{-6}$  cubic millimeters per second. A very considerable amount of work has been done upon the radium emanation by Ramsay and other men working with him. They have investigated

many of its properties and have discovered some very remarkable facts.

When the emanation acts on water it is found that oxygen and hydrogen are formed, the hydrogen being always in excess. The following table will give some of the results:

Weight of RaBr <sub>2</sub> H <sub>2</sub> O in solution.	Time of collection of gases.	Volume of gas.	Volume/gram/100 hours.	Excess of hydrogen.
<i>Grams.</i>	<i>Hours.</i>	<i>Cu. cm.</i>	<i>Cu. cm.</i>	<i>Per cent.</i>
.0600	168	2.88	28.6	4.44
.1090	240	8.91	31.0	8.65
.1090	386	16.43	44.9	6.13
.1000	158	5.09	30.3	8.76
.1000	168	4.93	29.3	7.22
.1620	48	3.18	41.8	7.88
			Mean . . . . .	5.51

The action of the emanation was exactly analogous to that of the radium salt itself. If the emanation is past into a mixture of oxygen and hydrogen, it will cause these two gases to combine to form water.

Ramsay and Collie have found that the emanation obeys Boyle's law quite closely. The following are a few of their results. Immediately after admitting the emanation the following readings were taken:

Temperature.	Pressure.	Volume.	V x P
<i>°C.</i>	<i>mm. †</i>	<i>cu. mm.</i>	
17.9	23.0	10.08	232
	53.5	5.04	269.5
	236.1	1.11	260.0
16.9*	195.7	.70	137.5
	70.7	2.03	143.1
	42.2	3.54	149.3
	18.2	8.39	152.7

\* 1½ hours later. † In millimeters of frequency.

The following figures show the sudden change in the volume of the emanation. On account of this sudden change of volume Ramsay and Collie believe that the emanation exists in two forms which they call emanation 1 and emanation 2. The results of their experiments indicate that the law of Charles is not obeyed.

Time, in minutes.	Volume in cubic millimeters.
0	.397
15	.351
22	.291
30	.247
45	.205
61	.199
95	.194

The experiments on the action of the radium emanation on water showed that the water was decomposed into oxygen and hydrogen, with always an excess of hydrogen. With the view that this might be pseudo-electrolysis, Cameron and Ramsay thought they would see what would happen when a copper solution was treated with the radium emanation. No copper was deposited; but on investigating the products it was found that a trace of lithium was present in the copper solution along with a considerable amount of sodium. This experiment was carried out during the summer of 1906, and the result was so unexpected and so important that the experiment has since been twice repeated, always with the same results.

In general, Cameron and Ramsay find that the dry emanation, decomposing spontaneously, produced an inactive gas which shows a brilliant spectrum of helium, with possibly a trace of neon. When the emanation is dissolved in water, neon and a trace of helium are produced, and when in a saturated copper sulphate solution, argon, a trace of neon, and lithium result.

TABLE 5.—Cameron and Ramsay's experiments.

Solution.	Nature of bulb.	Amount of emanation.	Time.	Removal of Cu.	Residues.	Results.
Experiment I. Saturated solution of copper sulphate recrystallized four times.	Soda-lime glass bulb.	Cu. mm. 3	Days. 30	H <sub>2</sub> S	Sodium and calcium.	Red line of lithium appeared.
Experiment II. Saturated solution of copper sulphate prepared by electrolysis.	Glass vessel.	3	30	H <sub>2</sub> S	1.1 mgs	Sodium spectrum and red lithium line.
Experiment III. Saturated solution of copper nitrate prepared chemically.	Platinum vessel.	1.5	41	H <sub>2</sub> S	2.48 mgs	Sodium and lithium spectra.
Experiment IV. Saturated solution of copper nitrate. (c) Extreme care was used in preparation of chemicals.	Vessels mostly of platinum and silica.	1.6	42	H <sub>2</sub> S	1.67 mgs	Residual gases. NO 1.12 cc. N <sub>2</sub> .84 cc. CO <sub>2</sub> .27 H <sub>2</sub> .44 cc. O <sub>2</sub> 1.12cc. Argon sodium, and lithium spectra.
(b) Control ex. Saturated solution of copper nitrate.	Vessels of platinum and silica.	.....	42	.....	.79 mgs	Sodium strong, no lithium present.
(c) Distilled water ..	Glass bulb.	1.44	38	.....	.71 mgs	N <sub>2</sub> . 307 cc. CO .065 cc. CO <sub>2</sub> .080 H <sub>2</sub> 3.74 O <sub>2</sub> 1.56cc. Brilliant neon spectrum. Sodium and potassium but no lithium.

Cameron and Ramsay have also tried passing the emanation into a lead nitrate solution, but were unable to get any spectrum of lithium. Experiment IV, which they made, was performed with all the care possible. During the first day the copper nitrate treated with the emanation became slightly cloudy, on the second day slightly green, after which the green did not become any more distinct. From this solution there was a greenish white deposit. The color of the untreated copper nitrate remained a clear blue thruout the experiment and gave no residual gas. The bulbs used were made from the same piece of glass tubing.

Cameron and Ramsay suggest that helium may result from the degradation of the large molecule of the emanation from its bombardment by the  $\alpha$  particles; that this degradation, when alone or with oxygen, results in the lowest member of the inactive series of elements, helium. If particles of greater mass are associated with the emanation as liquid water, then the degradation is less complete and neon is produced; when the associated molecules are still more complex, as copper sulphate, then the product is argon. These writers also believe that copper is also involved in this process of degradation and is reduced to the lowest member of its group of elements, namely, lithium. Whether sodium is also produced is difficult to say on account of its presence in the glass bulb used.

The above experiments, if verified, are fundamentally of the greatest importance, and the theory of radioactivity will now take on an entirely new phase. Previously all experimental data indicated that the process of disintegration of the elements was unaffected by any known physical or chemical methods. But here we have a process of controlling this transformation. Strutt's work on the occurrence of argon, neon, and helium in the rocks goes to partly confirm the work of Cameron and Ramsay.

## SUMMARY.

1. We have found that radium is a very remarkable element on account of its spontaneous emission of  $\alpha$ ,  $\beta$ ,  $\gamma$ , and  $\delta$  radiations.

2. It is an element that is rapidly disintegrating into products which have entirely different physical and chemical properties.

3. Radium is very widely distributed thruout the rocks of the earth, and exists in but small amounts in sea water.

4. It is quite possible that a part of the radium of the earth is of extra terrestrial origin.

5. The atmosphere contains several of the radium products.

6. Radium is a member of a family of elements which are disintegrating into a final product, lead.

7. The radium emanation evolves helium constantly.

8. Recent work indicates that under different conditions different elements are produced in the breaking down of the radium emanation. If this is true, it is quite possible that the argon, helium, and neon in the air may be due to the presence of radium.

## NOTES FROM THE WEATHER BUREAU LIBRARY.

By C. FITZHUGH TALMAN, Assistant Librarian.

## THE INTERNATIONAL METEOROLOGICAL COMMITTEE.

The reports of the meetings of the International Meteorological Committee—in English, French, and German—are published from six months to two years after the meetings; the English versions by the British Meteorological Office, the French usually by the Bureau Central Météorologique de France, and the German by either the Prussian Meteorological Institute, or the Zentralanstalt für Meteorologie at Vienna. We have recently received the German report of the meeting held in Paris last September.<sup>1</sup>

The sessions began Tuesday morning, September 10, the following members of the Committee being present: Hellmann, Lancaster, Mohn, Nakamura, Palazzo, Pernter, Rykachev, Shaw, and Hildebrandsson (secretary). Messrs. Angot and Hergesell were present as guests. In the absence of Professor Mascart, Doctor Shaw, director of the British Meteorological Office, acted as presiding officer. Prof. Mascart, President of the Committee, being detained at his home in Poissy by ill-health, invited the Committee to hold one of its sessions there, and the invitation was accepted.

A letter was read from Doctor Hann, presenting to the Committee his three memoirs on the daily march of temperature in the Tropic Zone, recently published by the Vienna Academy of Sciences. General Rykachev presented the report of the committee on terrestrial magnetism and atmospheric electricity, and also announced the appointment by the International Association of Academies of a committee charged with the execution of magnetic measurements along a parallel of latitude. Doctor Hergesell presented the report of the aeronautical committee. This report included a detailed account of the upper air observations made during the "international week" of July, 1907. Reference was also made to the inauguration of several new institutions for upper-air research; e. g., the Prussian observatory at Lindenberg, the observatory of the U. S. Weather Bureau at Mount Weather, and the private observatory of M. Riabouchinsky at Koutchino, Russia. Doctor Shaw reported that the observations with pilot balloons made at Cairo, Egypt, showed the occurrence of a steady west wind above the 1,200-meter level in that locality. A special committee was appointed to investigate the system of communicating weather information to vessels in use at the Zikawei Observatory, China, with a view to its universal adoption. A recommendation that the maximum and minimum temperatures in the past twenty-four hours be included in morning weather telegrams was adopted. A proposal by Doctor Shaw, looking to the adoption of a uniform scale and projection for daily weather maps and marine meteorological charts, to correspond with the requirements of dynamic meteorology, was approved in principle, but it was not deemed feasible to secure such uniformity at present.

The afternoon session was occupied with the important question of the publication of mean or normal values from the

<sup>1</sup> Bericht über die Versammlung des Internationalen meteorologischen Komitees, Paris, 1907. Berlin, 1908. (Veröffentlichungen des K. Preuss. Meteorologisches Instituts, Nr. 191).